



Hyperbolic metamaterials for midinfrared sensing

Shkondin, Evgeniy

Publication date:
2018

Document Version
Publisher's PDF, also known as Version of record

[Link back to DTU Orbit](#)

Citation (APA):
Shkondin, E. (2018). *Hyperbolic metamaterials for midinfrared sensing*. Poster session presented at 44th International conference on Micro and Nano Engineering, Copenhagen, Denmark.

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Large surface area Al-doped ZnO hyperbolic metamaterials for mid-infrared absorption spectroscopy applications

Evgeniy Shkondin, Taavi Rep  n, Mohammad Esmail Aryaee Panah, Andrei V. Lavrinenko, and Osamu Takayama
 Technical University of Denmark, Kgs. Lyngby, 2800, Denmark
 e-mail: eves@fotonik.dtu.dk

Keywords: mid-infrared absorption spectroscopy, hyperbolic metamaterials, transparent conductive oxides

Midinfrared (Mid-IR) light between 2.5-20 μm offers a unique advantage in biochemical sensing due to characteristic absorption features of target molecules in this wavelength region [1],[2]. The challenge is to detect low trace amounts of analytes due to the three orders of magnitude mismatch in sizes between Mid-IR wavelengths and molecules, resulting in weak absorption features of light.

The light absorption can be enhanced by implementing structures with a large surface area such as deep trenches, holes etc. Another, more peculiar approach is to use artificially designed materials with indefinite dispersion relation [3]. These are so-called hyperbolic metamaterials (HMMs), which are the class of strongly anisotropic artificial structures having their dielectric tensor components, the ordinary (ϵ_o) and extraordinary (ϵ_e) permittivity with opposite signs.

Recently, successful fabrication and optical characterization of large-area ($2 \times 2 \text{ cm}^2$), high aspect ratio AZO pillar- [4] and trench-based metamaterials [5] with the enlarged surface area have been realized.

Here, we report the enhancement of absorption in HMMs composed of high aspect ratio Al-doped ZnO (AZO) nanotrenches [6]. AZO is an alternative plasmonic material operating at the Mid-IR frequencies [7] with the possibility to tune optical response by adjusting the doping level for optimal sensitivity of molecules on demand.

High aspect ratio AZO trenches have been fabricated by means of deep-UV lithography, atomic layer deposition (ALD) and several dry etch techniques. The fabrication procedure is based on ALD deposition of AZO on sacrificial Si template with the sub-sequential removal of Si. The process is fully compatible with large-scale CMOS technology. The cross-sectional SEM image of the final structure is shown in Figure 1 (a). The inset depicts the hyperbolic regime at the wavelength above 2.7 μm .

The sensing ability of AZO trench HMM has been demonstrated by depositing 5 nm SiO_2 layer around the trenches using ALD in order to emulate the presence of organic molecules. The inset in Figure 1(a) presents a schematic illustration of AZO HMM architecture conformally covered with a SiO_2 layer, which has a characteristic absorption peak around 8 μm due to phonon absorption.

The reflection measurements were performed over a wavelength range from 6 to 10 μm with TM polarized light at $\theta=12^\circ$ angle of incidence. The AZO HMM covered with 5 nm SiO_2 exhibit a clear absorption as shown in Figure 1 (b). In order to highlight the enhancement, Figure 1 (c) presents the reflection difference of samples with and without SiO_2 . The difference in reflection is as high as 9.4%.

The absorption enhancement is achieved by a combination of large surface area of HMM structure and interaction of bulk plasmon modes propagating in the trenches. Since the structure is composed of multiple high aspect ratio (1:6.7) sub-wavelength AZO trenches on Si substrate, it provides 14.5 times more surface area for residing analyte molecules compared to the flat surface. Additionally, the incident light is known to invoke and interact with the bulk plasmon modes in HMM trench structure [5]. These facts play a pivotal role in the phenomenon of absorption enhancement. Our estimation is 5.7% of enhancement is due to the surface effects and the rest 3.7% to bulk plasmon contribution. We conclude that such plasmonic metamaterial structures can be designed to detect traces of target molecules in Mid-IR spectroscopy.

This work was supported by Villum Fonden ‘‘DarkSILD project’’ (11116) and Direkt  r Ib Henriksen’s Fond, Denmark. The authors would like to acknowledge the support from the Danish National Center for Micro- and Nanofabrication (DTU Danchip).

- [1] S. Law, V. Podolsky, D. Wasserman, Nanophotonics 2 (2013) 103-130.
- [2] J. Haas, B. Mizaiko, Annu. Rev. Anal. Chem. 9 (2016) 45-68.
- [3] A. Poddubny, I. Iorsh, P. Belov, Y. Kivshar, Nature Photon. 4 (2017) 2899-2907.
- [4] E. Shkondin, O. Takayama, M. E. Aryaee Panah, P. Liu, P. V. Larsen, M. D. Mar, F. Jensen, A. V. Lavrinenko, Opt. Mater. Express 7 (2017) 1606-1627.
- [5] O. Takayama, E. Shkondin, A. Bogdanov, M. E. Aryaee Panah, K. Golenitskii, P. Dmitriev, T. Rep  n, R. Malureanu, P. Belov, F. Jensen, A. V. Lavrinenko, ACS Photonics 4 (2017) 2899-2907.
- [6] E. Shkondin, T. Rep  n, M. E. Aryaee Panah, A. V. Lavrinenko, O. Takayama, ACS Appl. Nano Mater. 1 (2018) 1212-1218.
- [7] G. V. Naik, V. M. Shalaev, A. Boltasseva, Adv. Mater. 25 (2013) 3264–3294.

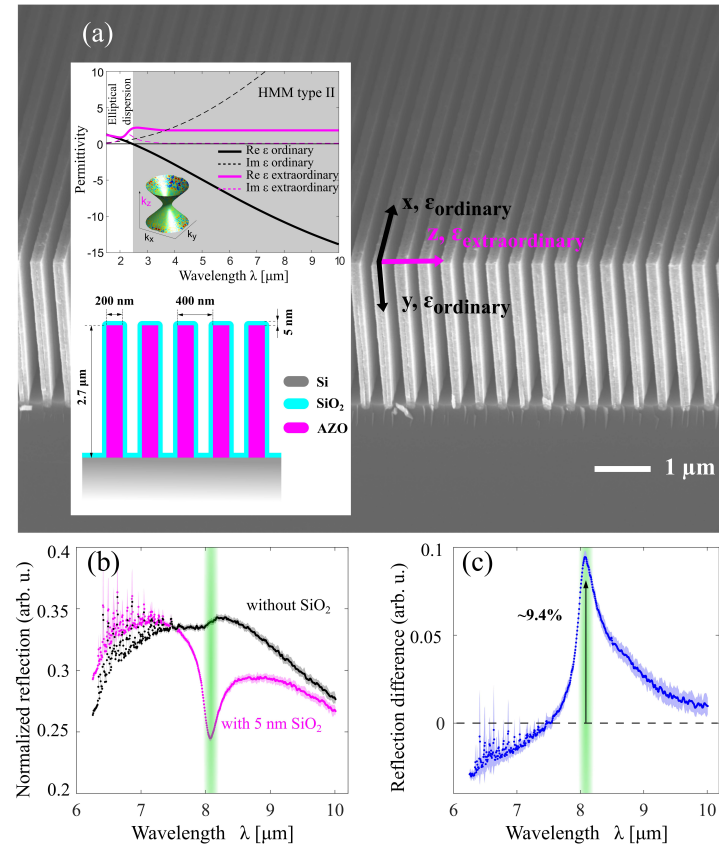


Figure 1. (a) Bird-eye-view SEM image of the fabricated AZO trench HMM, with permittivities shown by axis. The inset shows ordinary and extraordinary permittivities as a function of the wavelength and schematic illustration of AZO trench covered with 5 nm SiO_2 . (b) TM reflection from the structure with and without 5 nm SiO_2 at the incident angle of 12° . (c) Reflection difference demonstrating absorption enhancement above 9%. Color shade represents an error bar.